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RESEARCH MEMORANDUM

FREE-FLIGHT INVESTIGATION OF THE ROLLING EFFECTIVENESS OF SEVERAL DELTA WING - AILERON CONFIGURATIONS AT TRANSONIC AND SUPERSONIC SPEEDS

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FREE-FLIGHT INVESTIGATION OF THE ROLLING EFFECTIVENESS OF SEVERAL DELTA WING - AILERON CONFIGURATIONS AT TRANSONIC AND SUPERSONIC SPEEDS

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SUMMARY

As part of a general experimental investigation of wing-aileron rolling-effectiveness characteristics at transonic and supersonic speeds utilizing rocket-propelled test vehicles, several delta wing - aileron configurations were tested. The configurations tested included delta wings having 45° and 60° sweepback of the leading edge with constant-chord plain ailerons and a delta wing having 45° sweepback of the leading edge with delta wing-tip ailerons. The results show that, below a Mach number of 0.90, the rolling effectiveness of all the configurations tested was of the same magnitude. In the Mach number range from about 0.91 to just below 1.0 all configurations tested exhibited a reduction in effectiveness, as compared with that at a Mach number of 0.90, varying from 17 percent for the delta wing-tip ailerons to 50 percent for the constant-chord ailerons. With increasing supersonic Mach numbers, the rolling effectiveness of the delta wing-tip ailerons, which was about twice that of comparable constant-chord plain ailerons, tends toward a value which is about one-half of the subsonic effectiveness. A comparison between the measured values of rolling effectiveness and calculated values based on linearized supersonic-flow equations showed very good agreement for the delta wing-tip ailerons. For the constant-chord ailerons, the measured values were considerably smaller than the theoretical values. For the constant-chord-aileron configurations, the theory fairly accurately predicted the variation of effectiveness with Mach number.

INTRODUCTION

Of the several wing plan forms which have been proposed for flight at transonic and supersonic speeds, the delta plan form affords certain aerodynamic and structural advantages. Consequently, as part of a general investigation of the rolling-effectiveness characteristics of wing-aileron configurations at transonic and supersonic speeds being conducted by the Pilotless Aircraft Research Division of the

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Langley Laboratory utilizing rocket-propelled test vehicles in free flight, several wings of delta plan form having plain constant-chord ailerons and delta wing-tip ailerons were tested. These tests, which are reported herein, were made by means of the RM-5 technique (references 1, 2, and 3) with which the rolling capabilities of wing-aileron configurations can be evaluated over a large Mach number range (approximately 0.7 to 1.9) at relatively large scale. The present results permit a comparison of the rolling effectiveness of plain constant-chord ailerons and delta wing-tip ailerons on a delta wing and also show the effectiveness of plain constant-chord ailerons on delta wings having 45° and 60° leading-edge sweep.

SYMBOLS

$\frac{pb}{2V}$	wing-tip helix angle, radians
p	rolling velocity, radians per second
b	diameter of circle swept by wing tips
V	flight-path velocity
C_D	drag coefficient based on total exposed wing area of 1.563 square feet
A	exposed aspect ratio $\left(b_1{}^2/S_1\right)$
b_1	b minus fuselage diameter
S_1	exposed area of two wing panels
Λ_{LE}	sweepback of wing leading edge
δ_a	aileron deflection measured in plane normal to wing-chord plane and parallel to model center line
ϵ	semivertex angle of wing
μ	Mach angle $\left(\tan^{-1} \frac{1}{\sqrt{M^2 - 1}}\right)$

$$m \equiv \frac{\tan \epsilon}{\tan \mu} = \sqrt{M^2 - 1} \tan \epsilon$$

DESCRIPTION OF TECHNIQUE

Inasmuch as a complete discussion of the test technique is given in references 1, 2, and 3, only a brief description of the method will be given in this paper.

Test Vehicles

The geometric characteristics of the models of the present tests are given in figure 1 and table I. Photographs of the models are shown in figure 2. The models are constructed mainly of wood for ease of construction and lightness. The body is of balsa except at the wing attachment where spruce is used. The wings are constructed of laminated spruce with steel plates Cyclewelded into the upper and lower surfaces to provide adequate torsional rigidity. (See fig. 1.) The ailerons are formed by deflecting the basic-chord plane along the hinge lines shown in figure 1. This construction simulates a faired, sealed aileron in actual aircraft construction.

Tests

The launching of the test vehicles is accomplished at the Wallops Island test facility of the Pilotless Aircraft Research Division. The test vehicles are propelled by a two-stage rocket system to a Mach number of about 1.9. During a 12-second period of flight following rocket-engine burnout, in which time the test vehicles coast to a Mach number of about 0.7, measurements of the rolling velocity produced by ailerons (obtained with special radio equipment) and the flight-path velocity (obtained with Doppler radar) are made. These data, in conjunction with atmospheric data obtained with radiosondes, permit the evaluation of the rolling effectiveness of the particular wing-aileron configuration under investigation in terms of the parameter $\frac{pb/2V}{\delta_a}$ as a function of Mach number. In addition, the variation of drag coefficient with Mach number is obtained by a process involving the graphical differentiation of the curve of flight-path velocity against time for power-off flight. The relatively large scale of the tests is indicated by the curves of Reynolds number against Mach number shown in figure 3.

Accuracy

The accuracy is estimated to be within the following limits:

$\frac{pb/2V}{\delta_a}$ (due to limitations on model constructional accuracy) . . ±0.001

$\frac{pb/2V}{\delta_a}$ (due to limitations on instrumentation) . . . . ±0.0005

C_D . . . . ±0.003

M . . . . ±0.01

It should be noted, as pointed out in reference 1, that owing to the relatively small rolling moment of inertia the values of $\frac{pb/2V}{\delta_a}$ obtained during the larger part of the flight are substantially steady-state values even though the test vehicles are experiencing an almost continuous rolling acceleration or deceleration. Except for the Mach number range from about 0.9 to 1.1, where abrupt changes in rolling velocity usually occur, the correction to steady-state conditions is estimated to be within 3 percent. Inasmuch as it is not now possible to estimate the damping in roll with accuracy in the Mach number range from about 0.9 to 1.1, an accurate correction to steady-state condition cannot be made. However, for an extreme case having a rolling acceleration of 100 radians per second squared and a damping-moment coefficient of 0.1, the correction would be about 20 percent. No correction for inertia effects has been applied to the data presented herein.

RESULTS AND DISCUSSION

The results of the present investigation are shown in figure 4 as curves of the wing-aileron rolling-effectiveness parameter $\frac{pb/2V}{\delta_a}$ and drag coefficient C_D as a function of Mach number. In applying the present results which were obtained with three-wing configurations to configurations having other than three wings, consideration has been made of unpublished test results obtained with two RM-5 configurations having untapered wings of aspect ratio 3.0 and 0° and 45° sweepback which were tested in three-wing and four-wing arrangements. The rolling-effectiveness results for these three-wing and four-wing arrangements agreed well within the experimental accuracy, indicating that the interference effects in regard to rolling-effectiveness characteristics are probably negligible for the three-wing configurations of the present tests.

Wing-Aileron Rolling Effectiveness

Experimental results.- As shown in figure 4, below Mach number 0.90 the rolling effectiveness of all the configurations tested was of the same magnitude. In the Mach number range from about 0.91 to just below 1.0 all configurations tested exhibited a reduction in effectiveness varying from 17 percent for the delta wing-tip ailerons to 50 percent for the constant-chord ailerons on the delta wings with 45° leading-edge sweep. Of the configurations tested, the delta wing-tip-aileron configuration (model 84a) had the highest effectiveness and the smallest variation of effectiveness over the entire Mach number range. For this configuration, the effectiveness at the maximum Mach number attained ($M = 1.88$) was about one-half of the subsonic effectiveness. The rolling effectiveness of the comparable constant-chord plain-aileron configurations (models 97e and 97f) was about one-half of that for the delta wing-tip-aileron configuration at supersonic speeds.

An indication of the effect of leading-edge sweep of the delta wings on the rolling effectiveness of the constant-chord ailerons is shown by comparing the results for wings having 45° and 60° leading-edge sweepback, models 97e, 97f, 98a, and 98c, respectively. At the lower supersonic speeds, increasing the leading-edge sweep from 45° to 60° increased the rolling effectiveness. With increasing Mach number to the maximum attained, both configurations approached the same constant value of $\frac{pb/2V}{\delta_a}$.

Comparison with theory.- In figure 5, the experimental values of rolling effectiveness obtained for the configurations tested are compared with values calculated by methods based on the linearized flow equations. The theoretical characteristics of the delta wing - delta aileron configuration (model 84a) were obtained from reference 4 for the case of the Mach lines behind the leading edge (Mach numbers greater than 1.4). For the case of the Mach lines ahead of the leading edge (Mach numbers from 1 to 1.4) the characteristics were obtained from unpublished theory by Dr. Herbert S. Ribner of the Langley Laboratory. A similar theory is available in published form in reference 5. The theoretical characteristics of the constant-chord ailerons on delta wings (models 97 and 98) were obtained from reference 6 for the cases of Mach lines ahead of and behind the leading edge. In the theoretical calculations the damping in roll was obtained from reference 7 for all cases. The theoretical calculations, which in all cases applied to isolated wings only, were based on a wing plan form as defined in figure 6.

As shown in figure 5(a), good agreement exists between the theory and experiment for the delta wing - delta aileron configuration. It will be noted that the experimental values are larger than the theoretical values; this is attributed to the fact that, for the measured values, the part of the wing panels contained within the fuselage as shown in figure 6 cannot contribute to the damping. Consequently, inasmuch as the rolling moment due to the wing-tip aileron is relatively unaffected by the presence of the fuselage, the measured values of $\frac{pb/2V}{\delta_a}$ will be larger than the values calculated for a wing plan form as shown in figure 6.

For the constant-chord ailerons the experimental values of rolling effectiveness are considerably lower than the calculated values (fig. 5(b)). The lack of agreement is attributed partly to the wing and the fuselage boundary layer both of which have a larger adverse effect on the rolling moment due to aileron deflection than on the damping in roll. Also contributing to the lack of agreement between the theory and the experiment is the fact that the part of the wing panels contained within the fuselage cannot contribute to either the aileron rolling moment or to the damping in roll. Here, again, the aileron rolling moment is more adversely affected than the damping in roll. Finally, part of the lack of agreement can be attributed to the theory which ignores the effect of finite wing thickness. Rough calculations based on the results of reference 8 indicate that the theoretical-effectiveness values shown in figure 5(b) should be reduced by about 15 percent to account for the finite trailing-edge angle. In consideration of the aforementioned effects, the lack of agreement between theory and experiment appears to be reasonable. It should be noted that, as predicted by theory, the measured rolling effectiveness for both constant-chord-aileron configurations approaches the same constant value as the Mach number is increased to that value which causes the Mach lines to coincide with the leading edges of the wings.

Because absolute agreement between the present theory and experiment could not be obtained, an effort was made to establish whether the measured variation of $\frac{pb/2V}{\delta_a}$ with Mach number was that predicted by theory. At the suggestion of the author of reference 4, the results for the constant-chord ailerons were plotted as shown in figure 7. When this type of plot is used, the agreement is fairly good and indicates that the present theory, while incapable of predicting absolutely the wing - aileron rolling effectiveness, is useful in showing the variation of effectiveness with Mach number.

Drag

The variation of drag coefficient with Mach number for the models tested is shown in figure 4. Regardless of the aileron configuration, increasing the wing leading-edge sweep from 45° to 60° results in a marked decrease in total drag coefficient over the entire supersonic speed range investigated. By assuming, on the basis of tests reported in reference 9, a value of 0.026 for the drag coefficient of the fuselage at supersonic speeds, some indication of the variation of wing drag coefficient with leading-edge sweep can be obtained. At the higher supersonic speeds, the wing drag coefficient (taken as the difference between the measured drag coefficient and 0.026) of the delta wings with 60° leading-edge sweep is about one-half that of the delta wings with 45° leading-edge sweep. In examining these data, consideration should be made of the effects of section angle-of-attack distribution due to model rotation and wing-fuselage interference on the measured drag coefficients. It is believed, however, that these effects do not materially affect the foregoing estimated variation of wing drag coefficient with leading-edge sweep.

CONCLUSIONS

The following conclusions regarding the rolling effectiveness of delta wing - aileron configurations are indicated by the tests reported herein:

1. Below Mach number 0.90 all configurations tested exhibit the same magnitude of rolling effectiveness; from Mach numbers of 0.91 to just below 1.0 the effectiveness, as compared with that at a Mach number of 0.90, is reduced by 17 percent for the delta wing - delta aileron configuration and by 50 percent for the comparable constant-chord aileron configuration. The rolling effectiveness at supersonic speeds is lower than that at subsonic speeds for all configurations.

2. With increasing supersonic Mach numbers, the rolling effectiveness of the delta wing-tip ailerons tends toward a value which is about one-half of the subsonic effectiveness. The delta wing-tip aileron is about twice as effective as a comparable constant-chord aileron at supersonic speeds.

3. With constant-chord plain ailerons, increasing the sweepback of the wing leading edge from 45° to 60° results in an increase of rolling effectiveness which is a maximum at the lower supersonic speeds and which decreases as the Mach number increases. The rolling effectiveness for both configurations approaches the same constant value as the Mach number is increased to that value which causes the Mach lines to coincide with the leading edges of the wings.

4. For the wing-aileron configurations for which it is reasonable to assume that the effects of boundary layer are relatively small, such as the delta-aileron configuration of the present tests, it is possible to calculate the wing-aileron rolling characteristics with a good degree of accuracy by the use of the linearized supersonic-flow equations. For configurations such as the constant-chord-aileron configurations of the

present tests the boundary-layer effects and the effects of finite wing thickness are large enough so that the absolute theoretical values of rolling effectiveness based on the linearized theory will be considerably higher than the actual rolling effectiveness. The theory fairly accurately predicts the variation of effectiveness with Mach number.

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TABLE I

GEOMETRIC CHARACTERISTICS OF MODELS

Geometric characteristics	Model				
	84a	97e	97f	98a	98c
Airfoil section normal to chord plane and parallel to model center line	NACA 65A-006	NACA 65A-006	NACA 65A-006	NACA 65A-006	NACA 65A-006
Aileron deflection, δ_a, deg	5.0	5.5	4.9	5.0	5.0
Exposed wing area, S_1, sq ft	1.563	1.563	1.563	1.563	1.563
Ratio of aileron area to exposed wing area	0.20	0.20	0.20	0.20	0.20
Exposed aspect ratio, A	4.00	4.00	4.00	2.31	2.31
Wing leading-edge sweepback, deg	45	45	45	60	60
Moment of inertia about roll axis, slug-ft^2	0.080	0.087	0.083	0.078	0.074

NACA

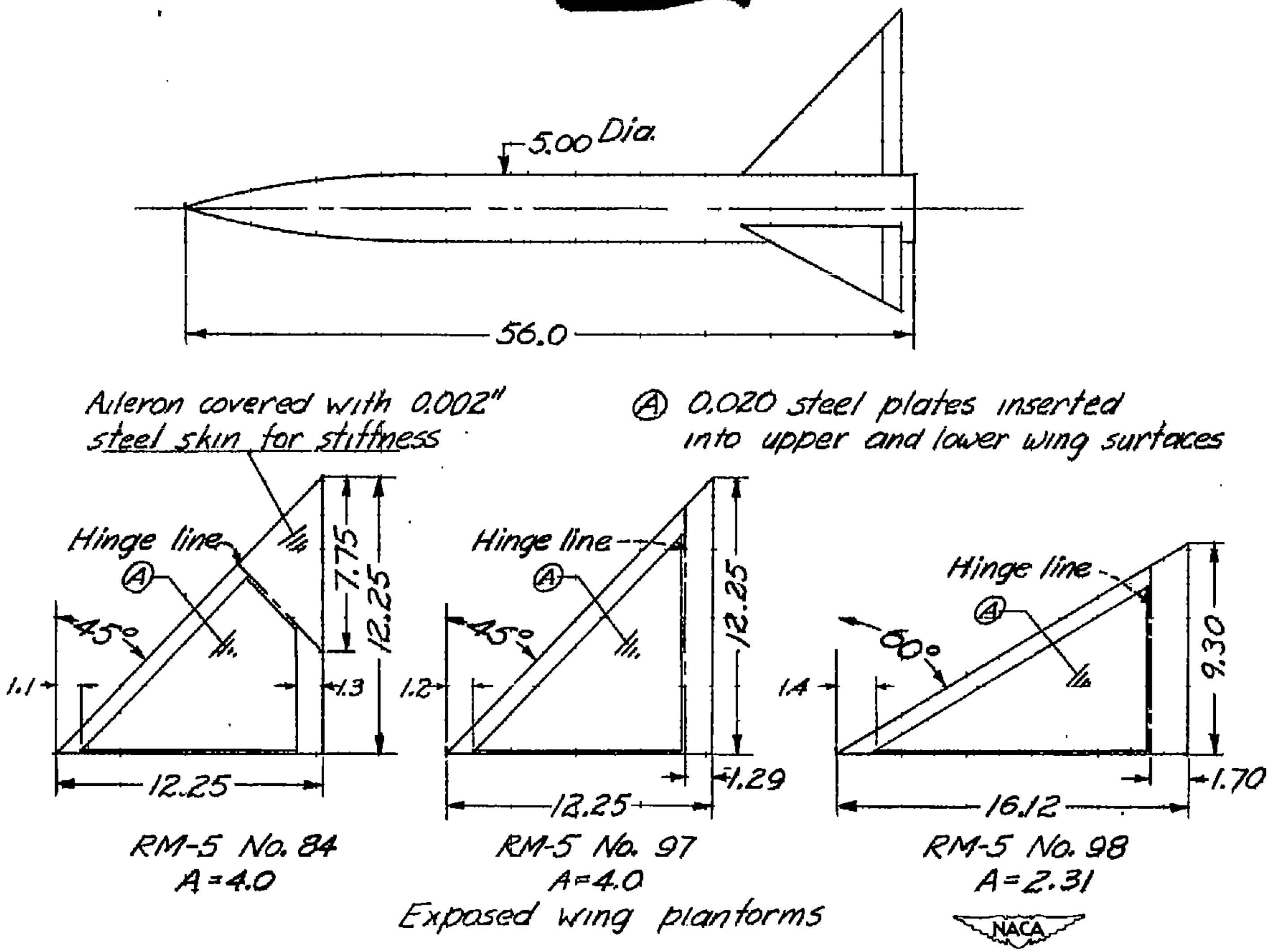

Figure 1.- General arrangement of RM-5 models.
Dimensions are in inches.

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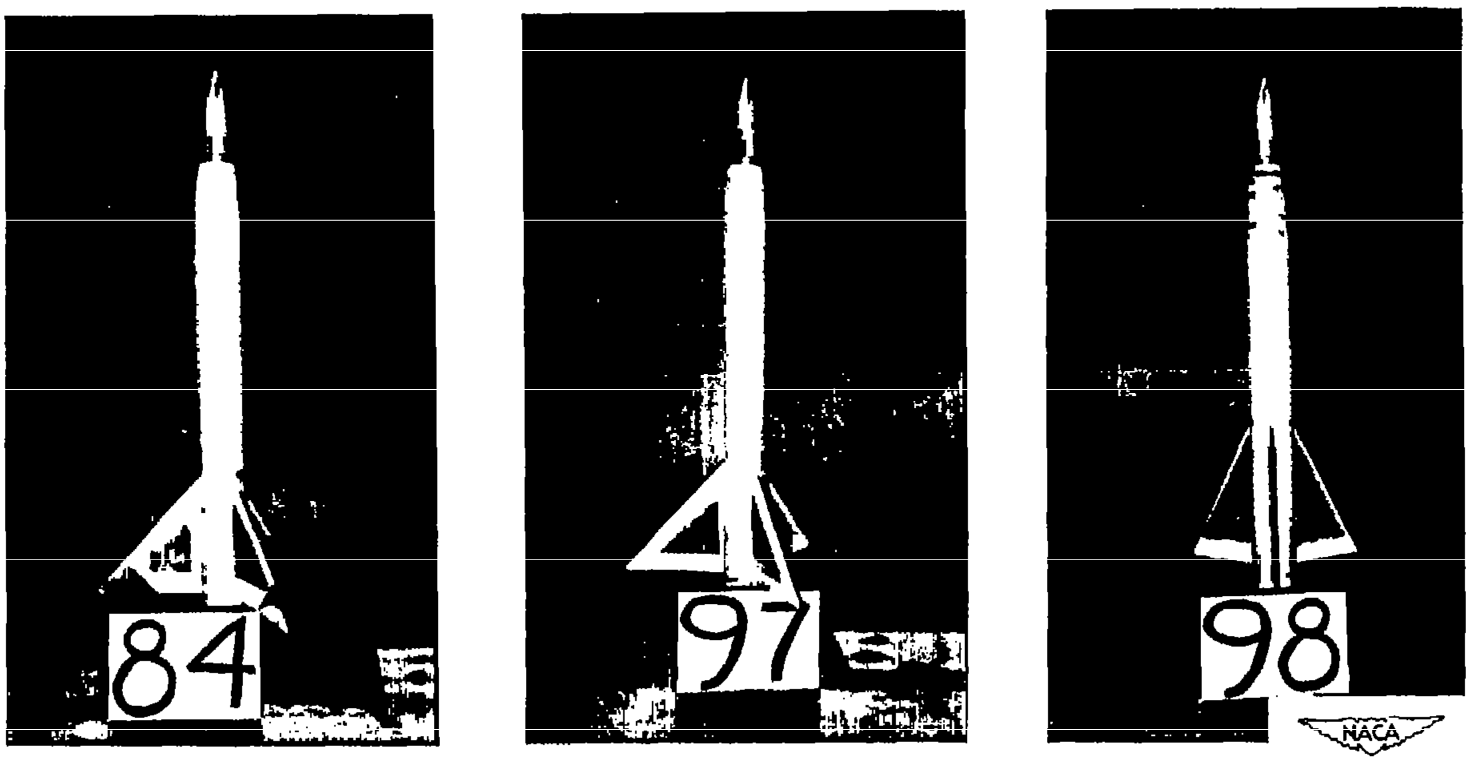

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Figure 2.- Model configurations of present tests.

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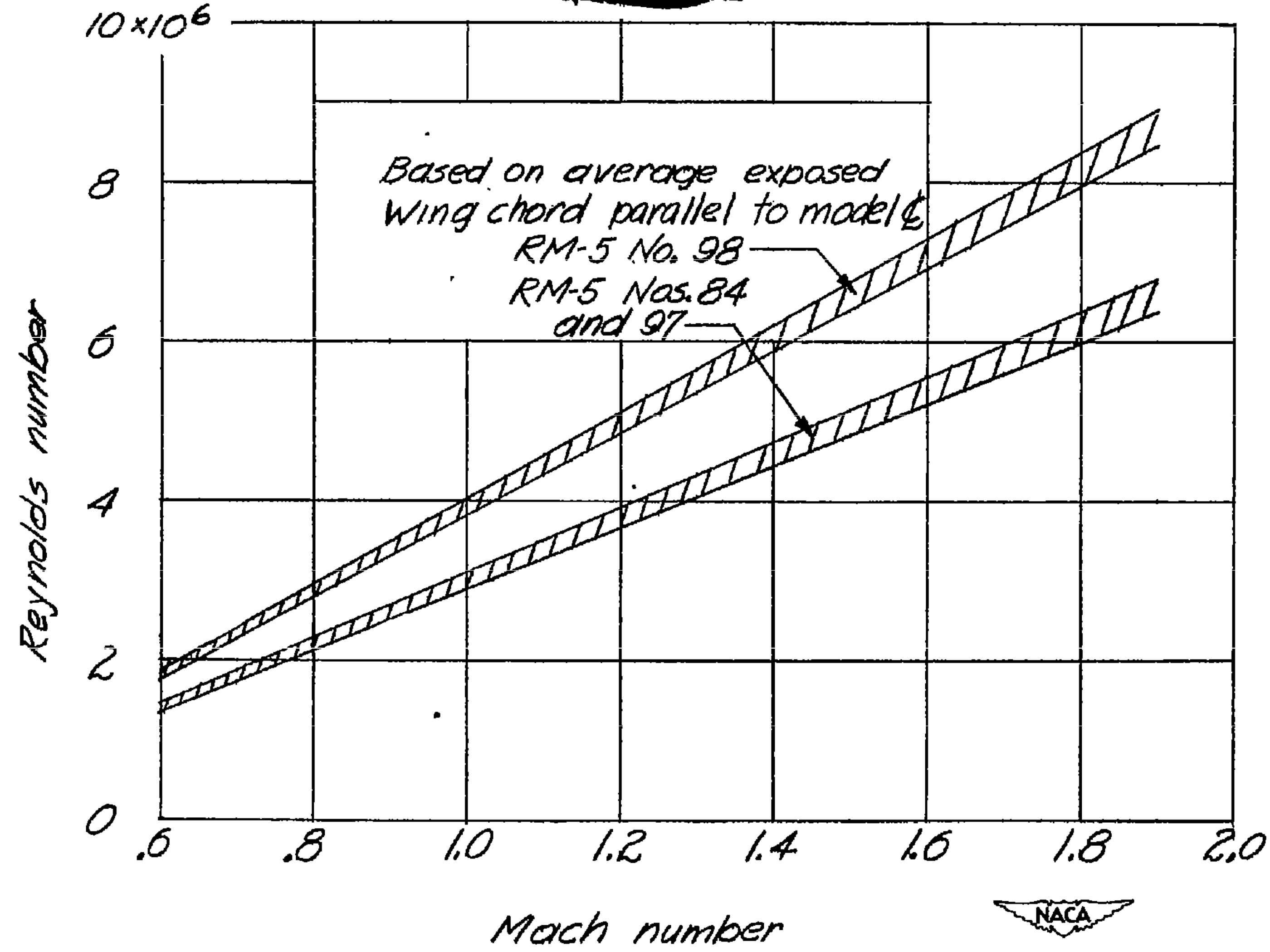

Figure 3.- Variation of Reynolds number with Mach number for the range of climatic conditions during tests.

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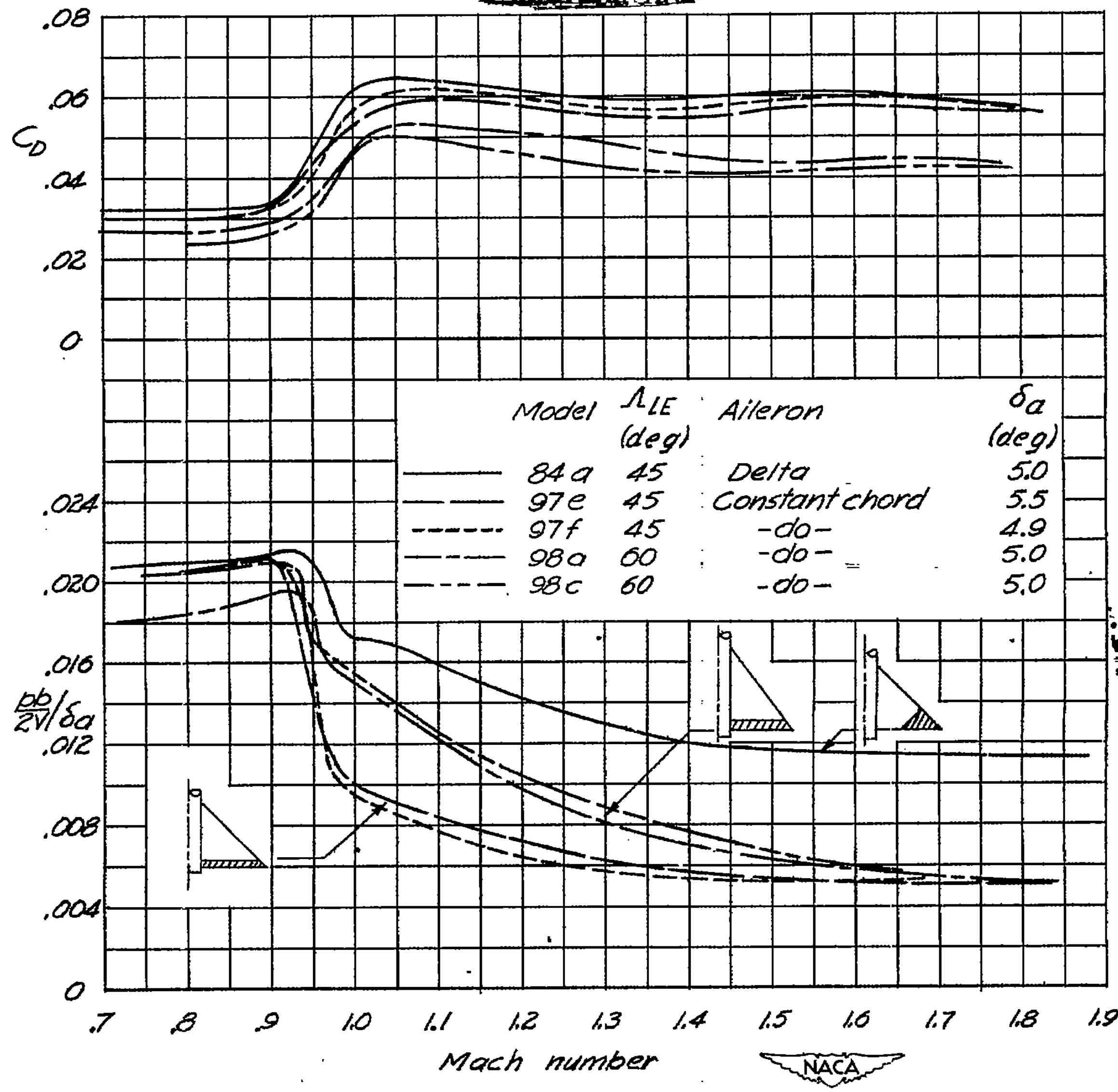

Figure 4.- Variation of $\frac{pb}{2V}/\delta_a$ and C_D with Mach number for configurations of present tests.

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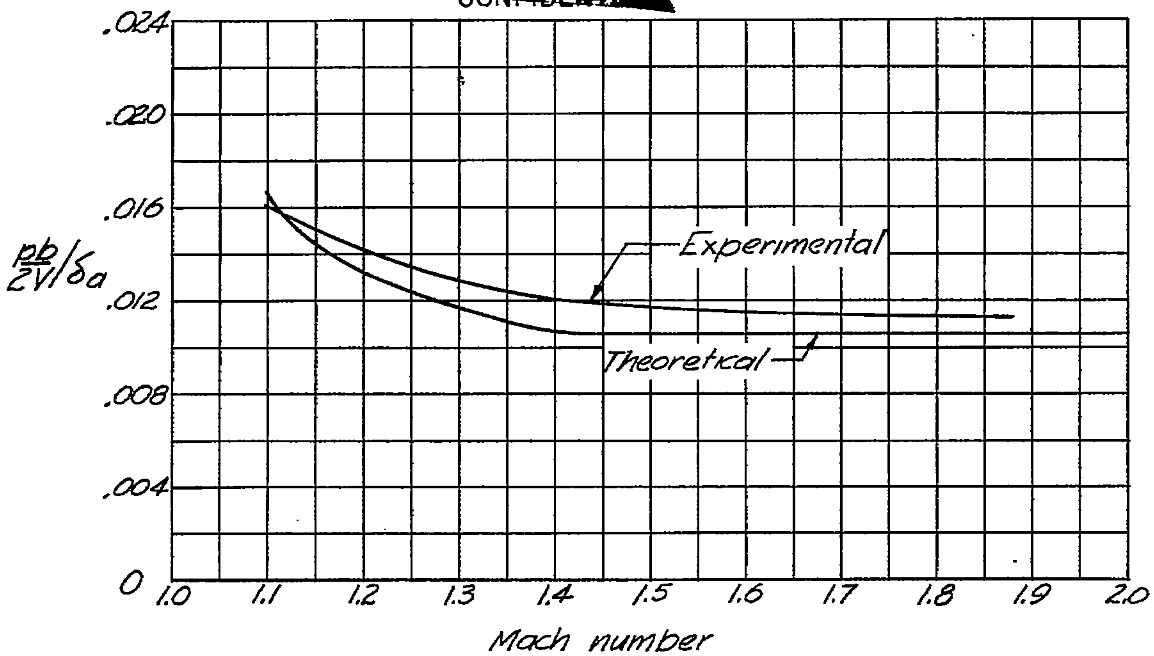
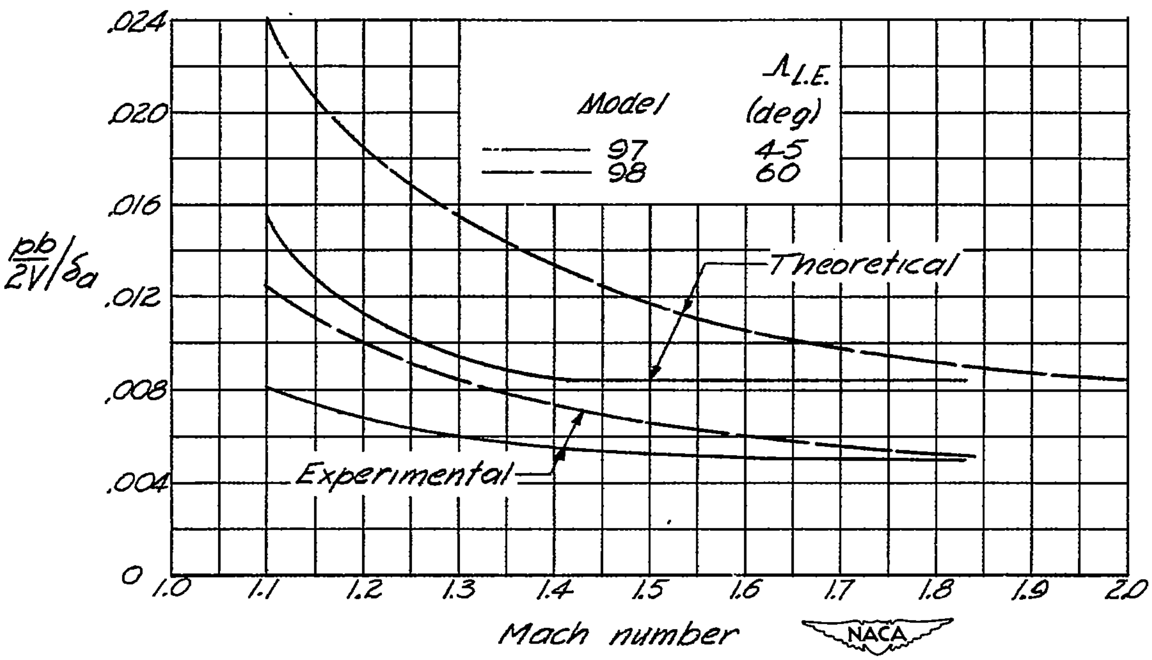


(a) Delta ailerons; $\Lambda_{L.E.}=45°$; model 84.



(b) Constant-chord ailerons. The experimental values are averages of 97e & f and 98 a & c, respectively.

Figure 5.- Comparison of experimental and theoretical results.

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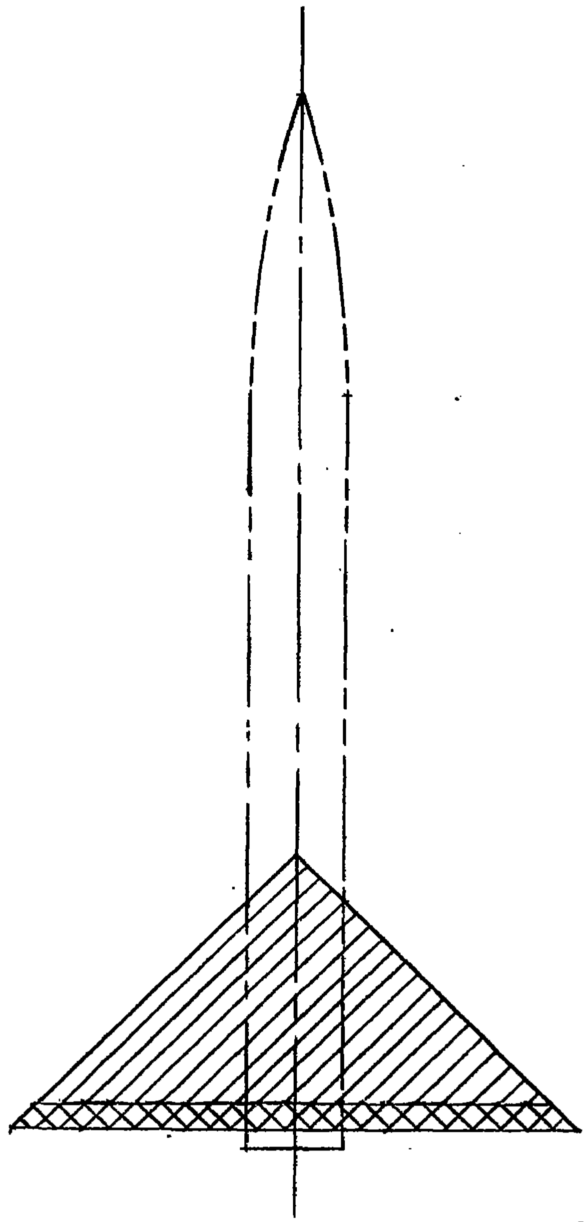

Figure 6.- Wing configuration considered in making calculations.

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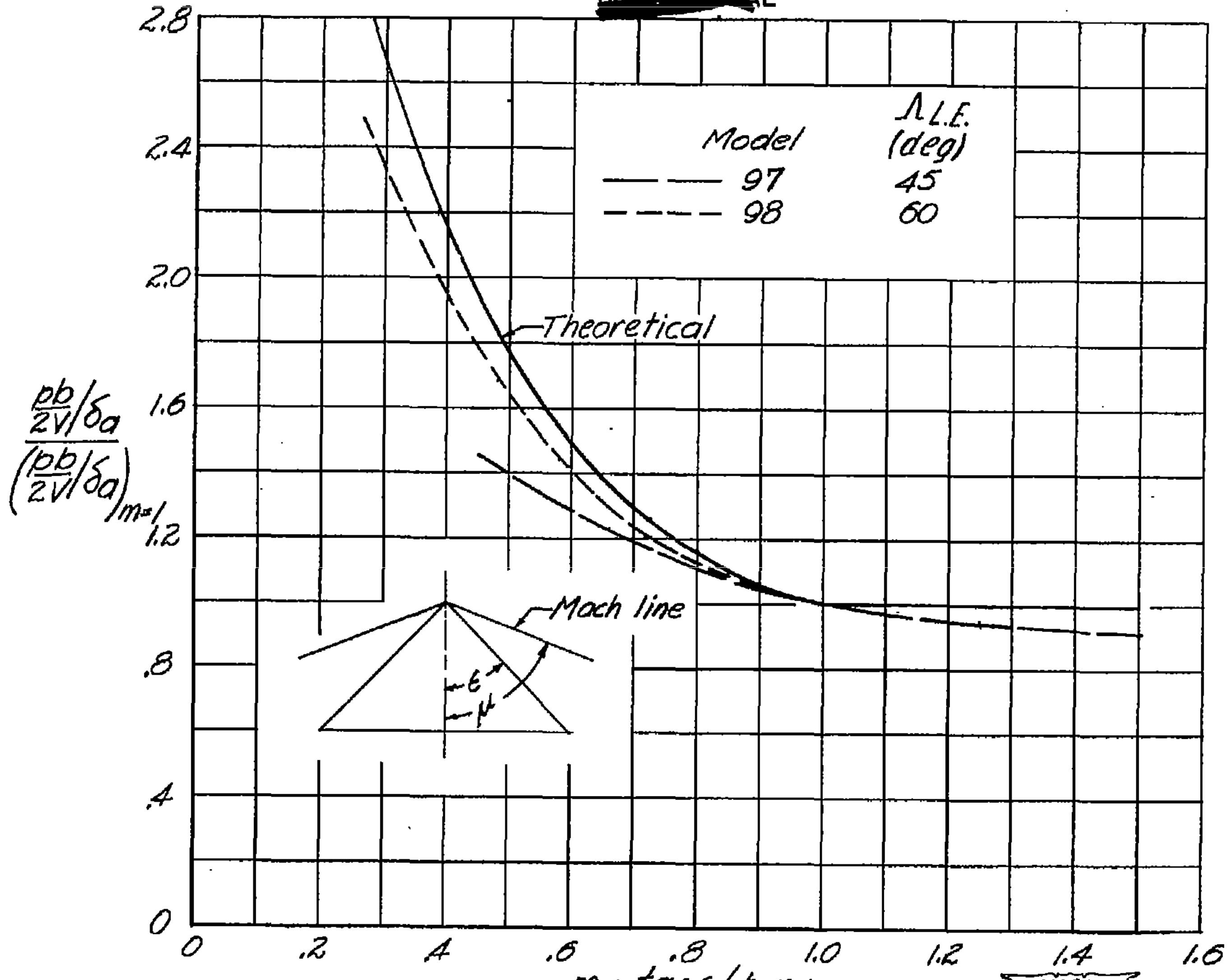

Figure 7.- Comparison of theoretical and experimental results. Constant-chord ailerons on delta wings.

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